UNITED STATES PATENT APPLICATION FOR:

TUBING EXPANSION

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ATTORNEY DOCKET NUMBER: CRUI/0012

CERTIFICATION OF MAILING UNDER 37 C.F.R. 1.10

I hereby certify that this New Application and the documents referred to as enclosed therein are being deposited with the United States Postal Service on March 25, 2004, in an envelope marked as "Express Mail United States Postal Service", Mailing Label No. EV335469013US, addressed to: Commissioner for Patents, Mail Stop PATENT APPLICATION, P.O. Box 1450, Alexandria, VA 22313-1450

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25 March 2004
Date of signature

PATENT
Attorney Docket No.: CRUI/0012
Express Mail No.:EV335469013US

TUBING EXPANSION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of Great Britain patent application serial number GB 0306774.1, filed March 25, 2003, Great Britain patent application serial number GB 0312278.5, filed May 29, 2003, and Great Britain patent application number GB 0316050.4, filed July 9, 2003 which are herein incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a device for use in tubing expansion and to methods of expanding tubing. In particular, but not exclusively, embodiments of the present invention relate to devices and methods for use in expanding tubing downhole.

Description of the Related Art

[0003] In the oil and gas exploration and production industry, bores drilled to access subsurface hydrocarbon-bearing reservoirs are lined with tubing, known as casing and liner. Furthermore, strings of tubing may be located within the cased bore to, for example, carry production fluid to surface. Recently, there have been numerous proposals to use tubing which is expanded downhole, that is tubing of a first diameter is run into a bore and then expanded to a larger second diameter. This offers many advantages to the operator, primarily providing the ability to create lined bores which do not necessarily suffer a loss in internal diameter each time a string of tubing is located in the bore, beyond an existing section of tubing-lined bore.

[0004] Early proposals for expanding tubing downhole featured the use of cones or mandrels, which are driven through the tubing in order to expand the tubing.

Other proposals include the use of roller expanders, some of which feature radially-urged rollers.

[0005] When tubing is expanded using a cone or mandrel, the expansion mode is different from when tubing is expanded using roller expanders. Typically, tubing expanded with a cone or mandrel tends to shorten in axial length whilst maintaining or suffering only a small reduction in wall thickness. Tubing expanded using roller expanders, however, tends to extend in axial length and experiences a reduction in wall thickness, caused by a wall thinning action.

[0006] These two different types of expansion devices offer various advantages and disadvantages depending upon the particular circumstances in which the device is employed.

[0007] Also, it is generally preferred to expand tubing in a top-down expansion procedure, as it is possible to recover the expansion device in the event that the tool becomes lodged in the tubing. However, when expanding tubing using an expansion cone or mandrel, it is conventional to employ a bottom-up expansion procedure. This is because it is necessary to apply a relatively large force on the cone from surface (by setting weight down on the cone), or to apply a relatively high pressure to the reverse face of the expansion cone (such as by supplying a pressurised fluid behind the cone), and it is not possible or safe to achieve the required loading or pressure on the cone in a top-down expansion procedure. This is particularly true for deviated (horizontal) wells and extended reach wells, where the forces required to expand tubing are, generally speaking, relatively high.

[0008] It is amongst the objects of embodiments of the present invention to provide improved devices and methods for use in expanding tubing downhole.

SUMMARY OF THE INVENTION

[0009] According to a first aspect of the present invention, there is provided a tubing expansion device comprising:

at least one expansion member adapted to expand a tubing by inducing a hoop stress in the tubing; and

at least one further expansion member adapted to expand the tubing by inducing a compressive yield of the tubing.

[0010] It will be understood that the hoop stress in tubing is the stress in the tubing wall acting circumferentially in a plane perpendicular to an axis of the tubing. Tubing expanded by induced hoop stress experiences a different expansion mode compared to tubing expanded by compressive yield whereby the tubing tends to axially contract in length. Tubing expanded by compressive yield, however, tends to axially extend in length and experiences a reduction in the tubing wall thickness. The invention thus allows the relative advantages of these different expansion modes to be combined in a single device.

[0011] The expansion device may be adapted to be translated through tubing to be expanded, and may be adapted to be rotated. Alternatively, the expansion device may be adapted to be advanced through tubing to be expanded without rotation.

[0012] Preferably, the hoop stress inducing expansion member and the compressive yield inducing expansion member are arranged such that expansion of the tubing to a desired final diameter is carried out by the compressive yield inducing expansion member. The applicant has found that tubing expanded by compressive yield demonstrates improved material properties, particularly crush resistance, when compared to tubing expanded by a hoop stress, as disclosed in the Applicant's corresponding UK patent application No.0216074.5, the disclosure of which is incorporated herein by way of reference. Alternatively, if desired or appropriate, expansion to a desired final diameter may be carried out using the hoop stress inducing expansion member.

[0013] Preferably, the hoop stress and compressive yield inducing expansion members are axially spaced, that is, axially separated, and/or circumferentially

spaced, that is, spaced around a perimeter or circumference of the expansion device. The expansion members may be relatively axially and/or rotationally arranged according to at least one parameter of a tubing to be expanded, which may be selected from the group comprising: a pre-expansion diameter and/or wall thickness of the tubing to be expanded; a desired post expansion diameter and wall thickness of the tubing; an initial strength (yield strength) of the tubing to be expanded; Young's Modulus of the tubing material; anticipated work hardening of the tubing during expansion (which depends upon factors including the tubing material); a desired post-expansion strength and degree of collapse or crush resistance of the tubing; and an anticipated or desired degree of axial extension or contraction in length of the tubing. This final parameter may depend upon factors including the likelihood of the tubing becoming differentially stuck. This can occur, for example, when there is a large differential pressure between high pressure fluid (such as drilling fluid) in a borehole surrounding the tubing, and a formation having a relatively low formation pressure, such as a particularly permeable formation. This can cause the tubing to become adhered or stuck to a wall of the borehole. Accordingly, by balancing the axial extension and contraction effects of the different expansion modes, the tubing can be expanded without any change in axial length.

[0014] The expansion members may be provided spaced alternately in an axial and/or rotational direction, and may be provided on separate portions or bodies, or as parts of separate tools, coupled together to form the expansion device. The expansion device may thus further comprise a hoop stress inducing expansion portion and a compressive yield inducing expansion portion, each carrying respective hoop stress and compressive yield inducing expansion members. The device may therefore be modular in nature, allowing a tool including a desired axial arrangement of the expansion tool portions, and thus of the hoop stress and compressive yield inducing expansion members, to be provided, according to particular requirements of the expansion device and, in particular, depending upon one or more parameter of the tubing to be expanded, as discussed above. The portions or tools may be coupled together, and may be restrained against relative rotation. Alternatively, at least one of said portions or tools may be rotatable relative

to at least one other portion or tool. Thus where the device is rotated and translated through tubing, at least one of said portions or tools may remain rotationally stationary relative to the tubing.

[0015] The hoop stress inducing expansion member may be adapted to contact the tubing over a majority of a circumference or perimeter of the tubing.

[0016] The compressive yield inducing expansion member may be adapted to contact the tubing over part of a circumference or perimeter of the tubing, and may contact the tubing in a point or line contact.

[0017] The expansion device may comprise a plurality of hoop stress inducing expansion members. Said expansion members may describe progressively increasing expansion diameters in a direction along an axial length of the device, to expand the tubing by progressively increasing degrees to a desired final diameter. The expansion device may additionally or alternatively comprise a plurality of compressive yield inducing expansion members. The compressive yield inducing expansion members may be arranged for movement to expansion positions describing progressively increasing expansion diameters in a direction along an axial length of the device. This may similarly facilitate expansion of the tubing to a desired diameter in progressive, incremental steps.

[0018] The expansion device may comprise a plurality of hoop stress and/or a plurality of compressive yield inducing expansion portions or tools, which may be axially alternating. Alternatively, a number of hoop stress inducing expansion portions may be coupled together and joined to one or more compressive yield inducing expansion portions, or vice versa, or indeed in any other suitable arrangement. In a further alternative, the expansion device may comprise at least one hoop stress inducing expansion member and at least one compressive yield inducing expansion member provided as a single tool, portion, body or part.

[0019] The hoop stress inducing expansion member may comprise a fixed expansion member. The hoop stress inducing expansion member may be fixed by

coupling or mounting the member with respect to a remainder of the device, for rotation with respect to the tubing. Alternatively, the hoop stress inducing expansion member may be rotatable with respect to the tubing and may, for example, be rotatably mounted on or to a body of the device, such as by a bearing, swivel or the like. Thus where the tool is rotated on translation through the tubing, the hoop stress inducing expansion member may remain rotationally stationary relative to the tubing, save for any rotation due to a reaction force imparted on the member by the tubing.

[0020] The hoop stress inducing expansion member may comprise a fixed diameter expansion member, such as a cone or mandrel, but may alternatively comprise a shoulder, arm, finger or the like. The expansion member may be formed integrally with or provided on or coupled to a body of the expansion device. Alternatively, the hoop stress inducing member may comprise a compliant expansion member such as a compliant cone, mandrel or the like, such as that disclosed in the applicant's International patent application no. PCT/GB2002/005387, the disclosure of which is incorporated herein by way of reference. It will be understood that a compliant expansion member is capable of inward deflection, for example, in the event that a restriction is encountered, such as an area of tubing which cannot be expanded.

[0021] The device may further comprise a hoop stress inducing expansion tool, portion or body including a plurality of hoop stress inducing members, which may take the form of expansion rollers mounted for rotation about an axis substantially perpendicular to an axis of the tool, as disclosed in PCT/GB2002/005387. The expansion tool or portion may alternatively comprise a tapered expansion cone or mandrel with a plurality of rotary expansion members, such as rollers, rotatably mounted on the tapered cone, as disclosed in the applicant's International patent publication no. WO 00/37766, the disclosure of which is also incorporated herein by way of reference.

[0022] The hoop stress inducing expansion member may take the form of a collapsible expansion cone, mandrel or the like, which may be movable between a collapsed and an expansion position, in the expansion position, the cone adapted for expanding the tubing.

[0023] The compressive yield inducing expansion member may comprise a rotary expansion member and may be rotatable with respect to the tubing. Preferably, the compressive yield inducing expansion member is rotatable relative to a body of the device about an expansion member axis.

[0024] The expansion device may be adapted to generate a drive force for translating the device with respect to or through the tubing. This may facilitate expansion of the tubing in a top-down procedure when, in an embodiment of the invention, using an expansion cone, mandrel or the like as the hoop stress inducing expansion member. The drive force may be generated on rotation of the expansion device. The compressive yield inducing expansion member may be adapted to generate a drive force on the tubing, the generated drive force serving for at least partly translating the device with respect to the tubing. The expansion device may be adapted to be translated through the tubing by a combination of an external axial force, which may be applied through a tubing string coupled to the device and the generated drive force, or the generated drive force may be sufficient to translate the device through the tubing without an externally applied axial force. An axis of the compressive yield expansion member may be skewed with respect to a body of the device. This may generate an axial drive force on rotation of the device. Where the device comprises a plurality of said expansion members, the members may be rotationally spaced and helically oriented with respect to a body of the device, as disclosed in WO 00/37766. The compressive yield inducing expansion member may be adapted to expand the tubing by a relatively small amount compared to the expansion generated by the hoop stress inducing expansion member. For example, the compressive yield inducing expansion member may expand the tubing by less than 50%, typically less than 25% and preferably by less than 10% of the total expansion achieved using the expansion device. The compressive yield inducing

expansion member may include a gripping surface for gripping the tubing to impart a drive force on the tubing, and may, for example, have a knurled or toothed gripping surface, or a combination thereof.

[0025] The expansion device may be adapted to be rotated from surface by rotation of a tubing string coupled to the device, or by a downhole motor such as a turbine, positive displacement motor (PDM), electrical motor or the like.

[0026] The compressive yield inducing expansion member may be provided as part of a compressive yield inducing expansion member module releasably coupled to a body of the device as a unit, and the compressive yield inducing expansion member may be rotatably mounted on a spindle. The spindle may comprise a cantilevered spindle extending from a body of the device. The expansion device may comprise a bearing between the compressive yield inducing expansion member and a body of the device, and a sealed lubrication system for containing lubricant to facilitate rotation of the compressive yield inducing expansion member relative to the body. The spindle may be pivotally coupled to the body. An axis of the spindle may be disposed at an angle with respect to a main axis of the tool.

[0027] The compressive yield inducing expansion member may be radially moveably mounted with respect to a body of the device, for movement towards an expansion configuration describing an expansion diameter for expanding tubing to a predetermined diameter. The expansion member may be lockable in the extended configuration. The expansion member may additionally or alternatively be biased radially inwardly. Thus in the absence of an expansion force exerted on the compressive yield inducing expansion member, the expansion member may be biased towards a retracted configuration. The expansion member may be moveable in response to both: a) an applied mechanical force; and b) an applied fluid pressure force. The expansion member may be pivotally mounted with respect to a body of the device for movement towards the extended configuration. The above features are disclosed in the Applicant's UK patent application No. 0220933.6, the disclosure of which is incorporated herein by way of reference.

[0028] According to a second aspect of the present invention, there is provided a method of expanding tubing, the method comprising the steps of:

expanding the tubing at least in part by inducing a hoop stress in the tubing; and

expanding the tubing at least in part by inducing a compressive yield of the tubing.

[0029] The method may comprise expanding the tubing at least in part by rotary expansion, but the tubing may alternatively be expanded without rotation.

[0030] The method may comprise providing an expansion device comprising a hoop stress inducing expansion member and a compressive yield inducing expansion member.

[0031] The method may comprise expanding the tubing to a first diameter by inducing one of a hoop stress in the tubing and a compressive yield of the tubing, and subsequently expanding the tubing to a second, greater diameter by the other one of inducing a hoop stress in the tubing and a compressive yield of the tubing. For example, the method may comprise providing at least one expansion member adapted to expand a tubing by inducing a hoop stress in the tubing; and at least one further expansion member adapted to expand the tubing by inducing a compressive yield of the tubing, and arranging said expansion members such that on translation of the tool through the tubing, expansion of the tubing to a first diameter is carried out using the hoop stress inducing expansion member, and expansion to a second, greater diameter is carried out using the compressive yield inducing expansion member, or vice versa.

[0032] The method may comprise arranging a hoop stress inducing expansion member and a compressive yield inducing expansion member relative to each other according to at least one parameter of tubing to be expanded, and the parameter may be selected from the group comprising: a pre-expansion diameter and/or wall thickness of the tubing to be expanded; a desired post expansion diameter and wall

thickness of the tubing; an initial strength (yield strength) of the tubing to be expanded; the Young's Modulus of the tubing material; anticipated work hardening of the tubing during expansion; a desired post-expansion strength and degree of collapse resistance of the tubing; and an anticipated or desired degree of axial extension or contraction in length of the tubing. In one embodiment of the invention, the method may comprise expanding the tubing without any or with negligible change in axial length of the tubing.

[0033] The tubing may be expanded by progressively increasing amounts to a desired final diameter, by providing a plurality of expansion members. The method may comprise providing a plurality of expansion tool portions, one expansion tool portion carrying at least one hoop stress inducing expansion member and another expansion tool portion carrying at least one compressive yield inducing expansion member. The expansion tool portions may be provided with a combination of hoop stress inducing compressive yield inducing expansion members.

[0034] The method may comprise providing a hoop stress inducing expansion tool or portion and a compressive yield inducing expansion tool or portion, each having a respective expansion member, selecting a desired axial arrangement of the expansion tools or portions and coupling the tools or portions together according to the selected arrangement. The arrangement may be selected according to said at least one parameter defined above.

[0035] The method may comprise inducing a hoop stress in the tubing by bringing an expansion member into contact with a majority of a circumference or perimeter of the tubing. The method may comprise inducing a compressive yield by bringing an expansion member into a line or point contact with the tubing, and rotating said expansion member around the circumference or perimeter of the tubing.

[0036] The method may further comprise rotating the expansion device to generate a drive force for at least partly translating the device through the tubing. In an embodiment of the invention, the method comprises providing a compressive

yield inducing expansion tool as disclosed in WO 00/37766, and with an axis of the compressive yield inducing expansion member at an angle with respect to a main axis of the device, and rotating said tool to generate the drive force. A hoop stress inducing expansion member such as a cone, mandrel or the like may be coupled to and thus driven by said expansion tool.

[0037] At least one of the hoop stress inducing and compressive yield inducing expansion members may have an expansion member axis, the axis disposed at an angle with respect to a main axis of the device. Where the compressive yield inducing expansion member comprises a rotary expansion member, said expansion member may be rotatable about an expansion member axis, said axis disposed at an angle with respect to a main axis of the device. The expansion member axis may converge with the tool main axis towards a leading end of the device. The compressive yield inducing expansion member may be rotatably mounted on a spindle, which may be disposed at an angle with respect to the device main axis, of the expansion member may include a spindle which is rotatable relative to a body of the device, the spindle disposed at an angle with respect to the device main axis.

[0038] According to a third aspect of the present invention, there is provided a method of expanding tubing, the method comprising the steps of:

determining at least one parameter of a tubing;

providing a tubing expansion device having at least one hoop stress inducing expansion member and at least one compressive yield inducing expansion member mounted for rotation with respect to a body of the tool, and with said hoop stress inducing expansion member and said compressive yield inducing expansion member provided in a desired arrangement relative to each other selected depending upon said parameter; and

translating the tubing expansion device through the tubing.

[0039] The step of providing said expansion device may comprise selecting the tubing expansion device from a group comprising a plurality of expansion devices

each having a different arrangement of said hoop stress and compressive yield inducing expansion members. Thus an expansion device may be selected which is most appropriate for expanding the tubing, depending upon said determined parameter.

[0040] Alternatively, the step of providing said expansion device may comprise assembling an expansion device with said hoop stress and compressive yield inducing expansion members provided in a desired arrangement selected depending upon said determined parameter.

[0041] The parameter may be selected from the group comprising a pre-expansion diameter and wall thickness of the tubing to be expanded; a desired post expansion diameter and wall thickness of the tubing; an initial strength (yield strength) of the tubing to be expanded; the Young's Modulus of the tubing material; anticipated work hardening of the tubing during expansion; a desired post-expansion strength and degree of collapse resistance of the tubing; and an anticipated or desired degree of axial extension or contraction in length of the tubing.

[0042] According to a fourth aspect of the present invention, there is provided a tubing expansion device comprising at least one fixed expansion member; and

at least one rotary expansion member mounted for rotation with respect to a body of the tool.

[0043] According to a fifth aspect of the present invention, there is provided a method of expanding tubing, the method comprising the steps of:

providing a tubing expansion device having at least one fixed expansion member and at least one rotary expansion member mounted for rotation with respect to a body of the tool; and

translating the tool through tubing to be expanded to expand the tubing in part by the fixed expansion member and in part by the rotary expansion member.

BRIEF DESCRIPTION OF THE DRAWINGS

[0044] Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[0045] Fig. 1 is a schematic view of a tubing expansion device in accordance with an embodiment of the present invention;

[0046] Fig. 2 is a view of the tubing expansion device of Fig. 1 shown in use;

[0047] Figs. 3, 4, 5, 5A, 5B, 5C, 5D and 5E are schematic views of tubing expansion devices in accordance with alternative embodiments of the present invention;

[0048] Fig. 6 is a view of a view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with an embodiment of the present invention;

[0049] Fig. 7 is a longitudinal sectional view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with an alternative embodiment of the present invention, the tool shown in a deactivated configuration and located in tubing to be expanded;

[0050] Fig. 8 is a view of the expansion tool of Fig. 7, drawn to a larger scale and shown in an expanded configuration during expansion of the tubing;

[0051] Fig. 9 is a view of the expansion tool of Fig. 7, shown in the deactivated configuration in alternative tubing to be expanded;

[0052] Fig. 10 is a view of the expansion tool of Fig. 9 in the expanded configuration, drawn to a larger scale and shown during expansion of the tubing;

[0053] Fig. 11 is a longitudinal sectional view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with a further alternative embodiment of the present invention, the tool shown in a deactivated configuration;

[0054] Fig. 12 is a view of the expansion tool of Fig. 11, drawn to a larger scale and shown in an expanded configuration;

[0055] Fig. 13 is a longitudinal sectional view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with a further alternative embodiment of the present invention, the tool shown in a deactivated configuration;

[0056] Fig. 14 is a schematic, bottom view of the expansion tool of Fig. 13 showing expansion members of the tool in both the de-activated and the expanded configurations;

[0057] Fig. 15 is a view of the tubing expansion tool of Fig. 13, drawn to a larger scale and shown in an expanded configuration;

[0058] Fig. 16 is a sectional view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with a further alternative embodiment of the present invention;

[0059] Fig. 17 is an end view of the tool of Fig. 16, showing the diameters described by the expansion members;

[0060] Fig. 18 is an enlarged sectional view showing details of the bearing arrangement between an expansion member and a spindle of the tool of Fig. 16;

[0061] Fig. 19 is a sectional view of an alternative expansion member for the tool of Fig 16;

[0062] Fig. 20 is a perspective view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with a further alternative embodiment of the present invention, with three of the five expansion members removed;

[0063] Fig. 21 is a front view of the tool of Fig. 20;

[0064] Fig. 22 is a sectional view on line 7 - 7 of Fig. 21;

[0065] Fig. 23 is an enlarged view of a portion of Figure 22;

[0066] Fig. 24 is an end view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with a further alternative embodiment of the present invention;

[0067] Fig. 25 is a sectional view on line 10 - 10 of Fig. 24;

[0068] Fig. 26 is a side view showing one half of the tool of Fig. 24;

[0069] Fig. 27 is a sectional view of an expansion tool forming part of any one of the expansion devices of Figs. 1 to 5E, in accordance with a further alternative embodiment of the present invention;

[0070] Figs. 28 and 29 are top and bottom views of the expansion tool of Fig. 27, respectively; and

[0071] Fig. 30 is a perspective view of the expansion tool of Fig. 27.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0072] Turning firstly to Fig. 1, there is shown a schematic view of a tubing expansion device in accordance with an embodiment of the present invention, the device indicated generally by reference numeral 10. The expansion device 10 is shown in Fig. 2 in use, during expansion of tubing in the form of an expandable liner 12. The expansion device 10 comprises at least one hoop stress inducing expansion member, in this embodiment, a fixed expansion member in the form of an expansion cone or mandrel 14 and at least one compressive yield inducing expansion member, in this embodiment, a rotary expansion member in the form of rotary expansion cone 16. The cone 16 is mounted for rotation with respect to a body 18 of the expansion device 10. The expansion device 10 is translated through the liner 12 to expand the liner to a greater diameter and, as will be described below,

this expansion is achieved in part by the mandrel 14 and in part by the rotary expansion cone 16.

[0073] In more detail, the expansion device 10 comprises two expansion tool portions in the form of a hoop stress inducing expansion tool portion 20 and a compressive yield inducing expansion tool portion 22. The expansion tool portion 20 includes a body 24 which is coupled to a string of tubing 26 for running the expansion device 10 into a borehole 28, the body 24 coupled to the tubing string 26 by, for example, a conventional pin and box type connection 30. The expansion cone 14 extends between the body 24 and the expansion tool portion 22, which may comprise one of a number of types of rotary expansion tools, as will be described below.

[0074] In Figs. 1 and 2, the compressive yield inducing expansion tool portion 22 comprises a rotary expansion tool having three rotary expansion cones 16, which are activated in response to applied fluid pressure to move from a retracted configuration (Fig. 1) to an extended, expansion configuration (Fig. 2), for expanding the liner 12.

[0075] Considering Fig. 2 in more detail, the expansion device 10 is shown run into a casing 32 previously located in the borehole 28 and cemented at 34, in a conventional fashion. The expandable liner 12 has been located within the casing 32 suspended, for example, through a temporary connection to the expansion device 10. The expansion device 10 is shown in Fig. 2 following activation and translation of the device part way through the liner 12. The device 10 is activated by supplying pressurized fluid to the device, to urge the rotary expansion cones 16 outwardly, and is rotated during translation through the liner 12. This causes an initial partial expansion of the liner 12 to a first diameter d1, as indicated by the area 36 in Fig. 2.

[0076] The expansion device 10 is translated through the liner 12 in a top-down expansion procedure, thus following initial expansion to the diameter d1, the liner 12 is then expanded to a greater diameter d2 by the expansion cone 14. This is

achieved by exerting a relatively large axial force on the device 10, for example, by setting weight down upon the expansion device 10 from surface through the tubing string 26. This process is continued until the liner 12 has been expanded over a desired length, and the expansion device 10 is then deactivated and recovered to surface.

[0077] The liner 12 may act as a liner extending from a shoe of the casing 32 (the lowermost casing section), for gaining access to a hydrocarbon bearing formation. However, it will be understood that the tubing 12 may equally take the form of a straddle/patch or other solid tubing, or a sand exclusion based tubing assembly such as the applicant's ESS (Trademark) sandscreen, of the type disclosed in International Patent Publication No WO97/17524.

[0078] Turning now to Fig. 3, there is shown a view of a tubing expansion device in accordance with an alternative embodiment of the present invention, the device indicated generally by reference numeral 110. Like components of the expansion device 110 with the device 10 of Figs. 1 and 2 share the same reference numerals, incremented by 100. For brevity, only the differences between the devices 110 and 10 will be described herein in detail.

[0079] The expansion device 110 includes a hoop stress inducing expansion tool portion 120 comprising three separate expansion mandrels 114, 114', 114" which are of progressively increasing maximum external diameter in a direction along a main axis 37 of the device away from a nose 38 of the tool. In use and during translation of the expansion device 110 through tubing, such as the liner 12 of Fig. 2, expansion of the liner out to a final diameter (such as the diameter d2) is achieved progressively, each expansion cone 114, 114', 114" providing a small increase in the diameter of the tubing.

[0080] Fig. 4 is a view of a tubing expansion device in accordance with a further alternative embodiment of the present invention, the device indicated generally by reference numeral 210. Like components of the expansion device 210 with the device 10 of Figs. 1 and 2 share the same reference numerals, incremented by 200.

For brevity, only the differences between the devices 210 and 10 will be described herein in detail.

[0081] The expansion device 210 includes two compressive yield inducing expansion tool portions 222, 222' which are axially spaced along the expansion device 210, and a hoop stress inducing expansion tool portion 220 comprising expansion cone 214, which extends between the rotary portions 222 and 222'.

[0082] The expansion tool portion 222' includes three rotary expansion cones 216' (one shown in Fig. 4) which describe a larger expansion diameter than the cones 216 of the expansion tool portion 222. Translation of the expansion device 210 through tubing such as the liner 12 of Fig. 2 provides a progressive increase in diameter of the tubing out to a maximum diameter determined by the rotary expansion cones 216'. The arrangement of the expansion device 210 is such that final expansion of the tubing is by the expansion cones 216', offering advantages over fixed diameter mandrels or cones. This is the applicant has been found that mechanical properties of tubing expanded using a rotary expansion tool, such as the expansion tool portion 222', exhibit different characteristics, such as improved post expansion strength and work hardening characteristics, compared to tubing expanded using cones or mandrels.

[0083] Turning now to Fig. 5, there is shown a tubing expansion device in accordance with a yet further alternative embodiment of the present invention, the device indicated generally by reference numeral 310. Like components of the expansion device 310 with the device 10 of Figs. 1 and 2 share the same reference numerals, incremented by 300. For brevity, only the differences between the devices 310 and 10 will be described herein in detail.

[0084] The expansion device 310 includes a hoop stress inducing expansion portion 320 comprising a mandrel 314 at a leading end 338 of the device, for expanding tubing such as the liner 12 to a first diameter. The device also includes a compressive yield inducing expansion tool portion 322, axially spaced from

mandrel 314, and comprising rotary expansion cones 316, for expanding the liner to a second greater diameter.

[0085] Turning now to Figs. 5A and 5B, there are shown tubing expansion devices in accordance with yet further alternative embodiments of the present invention, the devices indicated generally by reference numerals 410 and 510, respectively. Like components of the expansion devices 410 and 510 with the device 10 of Figs. 1 and 2 shares the same reference numerals, incremented by 400 and 500, respectively. For brevity, only the differences between the devices 410/510 and 10 will be described herein in detail.

[0086] Fig. 5A is a schematic view of the expansion device 410, which includes a hoop stress inducing expansion tool portion 420 having an expansion cone 414, and a compressive yield inducing expansion tool 422 having a plurality of rotary expansion cones 416. The rotary expansion cones 416 are mounted at a leading end of the expansion cone 414 for carrying out an initial expansion of tubing such as the liner 12, followed by expansion to a desired final diameter by the expansion cone 414. The expansion device of Fig. 5B is similar to the device 410 of Fig. 5A, except the device 510 includes a hoop stress inducing expansion tool portion 520 having an expansion cone 514 at a leading end of the device, with a compressive yield inducing expansion tool 522 having a plurality of rotary expansion cones 516 at a trailing end of the expansion cone 514, for expanding the tubing to a desired final diameter.

[0087] Turning now to Fig. 5C, there is shown an expansion device 610 in accordance with a further alternative embodiment of the present invention. The expansion device 610 is similar to the expansion device 10 of Fig. 1, and like components share the same reference numerals, incremented by 600. In a similar fashion to the device 10, the device 610 includes a compressive yield inducing expansion tool 622 of a type disclosed in WO 00/37766, the expansion tool 622 acting as a tractor. In the illustrated embodiment, the rotary expansion rollers 616 are mounted in the tool body 618 with their axes skewed with respect to a main axis

of the device 610, in a helical configuration. An expansion cone 614 is coupled to the expansion tool 622 optionally via a swivel 625 and, on activation and rotation of the expansion tool 622 within tubing such as the liner 12, the expansion rollers 616 generate a drive force on the liner 12 to pull the expansion cone 614 through the liner 12. The swivel 625 allows the expansion cone 614 to be advanced through the liner 12 with little or no rotation. The rollers 616 cause a partial expansion of the liner 12, however, the primary expansion is by the expansion cone 614. The rollers 616 optionally have knurled, toothed or otherwise shaped or textured gripping surfaces 46, to improve grip with the liner 12.

[0088] The expansion device 610 is rotated either from surface through a string of tubing (not shown) coupled to the compressive yield inducing expansion tool 622, or by a downhole motor such as a turbine, PDM or electrical motor. The expansion device 610 thus acts as a tractor for the expansion cone 614 and allows tubing such as the liner 12 to be expanded in a top-down expansion procedure utilizing an expansion cone or mandrel, overcoming problems associated with prior proposals.

[0089] In particular, as noted above, solid cone expansion forces are high, and expansions are typically performed from the bottom up because it is not possible (or safe) to achieve the required set down weight to go from the top down in most applications. However, by utilizing the expansion tool 622 as a tractor and thus by applying the tractor load as close to the cone 614 as possible, this reduces the surface loads needed to complete cone expansion.

[0090] Turning now to Fig. 5D, there is shown an expansion device 710 in accordance with a further alternative embodiment of the present invention, shown in partial longitudinal cross-section. The expansion device 710 is essentially similar to the expansion device 310 of Fig. 5, except the device 710 includes a hoop stress inducing expansion tool having an expansion cone 714 rotatably mounted on a body 718 of the device 710 by a bearing (not shown). This facilitates translation of the expansion device 710 through tubing to be expanded, such as the liner 12, with little or no rotation of the cone 714 relative to the liner 12.

[0091] Turning now to Fig. 5E, there is shown an expansion device 810 in accordance with a further alternative embodiment of the present invention. The expansion device 810 is similar to the expansion device 10 of Fig. 1 and like components with the expansion device 10 share the same reference numerals, incremented by 800.

[0092] The expansion device 810 includes a hoop stress inducing expansion tool 820 having a tapered support mandrel 814 with two sets of expansion rollers 48, 48' mounted with their axes perpendicular to a main axis of the device 810. The sets of expansion rollers 48, 48' describe progressively increasing expansion diameters and may be compliant. The hoop stress inducing expansion tool 820 is connected via a swivel 50 to a compressive yield inducing expansion tool 722, and on activation of the device 810 and translation through the liner 12, there is little or no rotation of the cone 814 relative to the liner 12.

[0093] As discussed above, expansion of tubing by inducing a hoop stress in the tubing using a cone or mandrel tends to cause an axial contraction in the length of the tubing, whilst expansion by inducing a compressive yield using rotary expansion tools tend to thin the wall of tubing and cause an axial extension. Thus, by providing a combination of hoop stress and compressive yield inducing expansion members in the expansion devices 10 to 810 of Figs. 1 to 5E, it is possible to combine these expansion modes to achieve expansion of the liner 12 without causing extension or contraction of the liner. Also, if desired, a more controllable extension or contraction of the liner can be achieved by balancing the effects of the hoop stress and compressive yield inducing expansion members.

[0094] In a further alternative embodiment not illustrated herein, an expansion device may be provided combining the theories of any of Figs. 1 to 5E. For example, the expansion device 110 of Fig. 3 may comprise a plurality of rotary expansion tool portions 122, which may be provided in series or axially spaced between expansion cones such as the cones 114, 114' and 114". Alternatively, a device may be provided comprising any desired configuration or pattern of hoop

stress and compressive yield inducing expansion cones, which may be spaced axially and/or rotationally around a body of the device.

[0095] Furthermore, the particular arrangement or configuration of the hoop stress and compressive yield inducing expansion cones may be selected according to one or more determined parameters of the tubing to be expanded. These parameters may include the diameter and wall thickness of the tubing to be expanded; the initial yield strength of the tubing to be expanded; the Young's Modulus of the tubing material; the anticipated work hardening experienced by the tubing during expansion (which depends upon factors including properties of the material from which the tubing is formed); the desired end result in terms of the desired final strength and collapse resistance of the tubing; and the desired final length of the tubing, which depends upon the particular combination of hoop stress and compressive yield inducing expansion members used, as described above. This final parameter may be of particular interest where it is desired to avoid differential sticking of tubing, such as in an open hole environment. This is because the forces required to overcome differential sticking can cause problems with conventional expansion devices, such as failure of connections between sections of liner tubing.

[0096] Turning now generally to Figs. 6 to 36, there are shown various views of tubing expansion tools incorporating rotary expansion members, of types suitable for forming the rotary expansion tool portion 22 to 822 of any one of Figs. 1 to 5E, respectively.

[0097] Turning initially to Fig. 6, there is shown a longitudinal half-sectional view of a rotary expansion tool 22a, which takes the form of the applicant's commercially available rotary expansion tool, manufactured according to the principles of International patent publication No. WO 0/37766, the disclosure of which is incorporated herein by way of reference. Each rotary expansion cone 16a is rotatably mounted on a spindle 40a, which is in turn mounted on a piston 42a for movement between a retracted position shown in the left half of Fig. 6 and an

extended, expansion position, shown in the right half of Fig. 6. The expansion tool 22a includes three such rotary expansion cones 16a spaced around the circumference of the tool body 18a.

[0098] Turning now to Fig. 7, there is shown a longitudinal sectional view of an alternative tubing expansion tool 22b. The tool 22b is shown located in a liner 12b which is to be diametrically expanded. The expansion tool 22b is shown in Fig. 7 in a de-activated configuration.

[0099] The expansion tool 22b comprises a hollow body 14b and four expansion members 16b, each radially moveably mounted on the body 14b, for movement towards an extended configuration describing an expansion diameter, as shown in Fig. 8. Each expansion member 16b includes an oval section expansion roller 18b mounted on a piston 20b, which is radially moveable in slots 22b in a tapered lower end 24b of the body 14b. Alternatively, the roller 18b is mounted in a body or housing pivotably mounted to the tool body 14b, for example, by a pivot such as the pivot 25b shown in the drawings.

[00100] A hollow activating mandrel 26b is mounted in the body 14b for urging the rollers 18b to the extended configuration of Fig. 8. The mandrel 26b is moveable between a deactivating position shown in Fig 7 and an activating position shown in Fig 8, in response to either an applied mechanical force, an applied fluid pressure force or a combination of the two. A lower end 52b of the mandrel 26b is truncated cone-shaped, and defines a cam surface 54b for urging the rollers 18b to the extended configuration, as will be described below. The expansion tool 22b also includes a locking assembly 35b comprising a snap ring 27b located in a groove 29b in the mandrel 26b, for locking the rollers 18b in the extended configuration of Fig 8.

[00101] An upper end 28b of the mandrel 26b is coupled to a connecting sub 30b which allows a mechanical force to be exerted on the mandrel 26b to move the mandrel between the deactivating and activating positions. The connecting sub 30b is in-turn coupled to, for example, the mandrel 14 of the tool 10 (Fig. 1), and the sub 30b is axially moveable relative to the body 14. The tool 10 also includes a biasing

member comprising a spring 36b, which biases the mandrel 26b towards the deactivating position of Fig 7. In the deactivating position, the mandrel 26b de-supports the rollers 18b, allowing the rollers to be moved radially inwardly, towards the retracted position of Fig. 7.

[00102] The biasing spring 36b is located between a shoulder 38b in the body 14b and a shoulder 40b of the connecting sub 30b. As will be described below, when the force on the mandrel 26b is removed or reduced, the spring 36b urges the sub 30b and mandrel 26b towards the deactivating position of Fig. 7, to de-support the rollers 18b.

[00103] The tool body 14b includes an annular guide ring 42b which guides the mandrel 26b and a cylinder 44b are defined by an annular floating piston 46b mounted between the mandrel 26b and the body 14b. The mandrel 26b includes a number of ports 48b extending through the wall of the mandrel which allow fluid communication between a central bore 50b of the tool 22b and the cylinder 44b. Seals (not shown) are provided between the piston 46b and a shoulder 37b of the mandrel 26b such that the piston defines an upper piston area 29b and a smaller, lower piston area 31b, and further seals 58b, 60b are provided above and below the cylinder 44b.

[00104] The seals 58b, 60b ensure that pressure is applied to the upper piston area 29b and that there is no leakage into the chamber of spring 36b, or past the piston 46b. Also, a flow restriction nozzle 33b is provided at the lower end of the mandrel 26b. As will be described below, both the differential piston area and the nozzle 33b allow movement of the mandrel 26b by application of fluid pressure, to urge the rollers 18b to the extended configuration. Flow ports 62b in the cone 52b allow flow of cooling fluid to the rollers 18b during expansion of the liner 12b.

[00105] A method of operation of the expansion tool 22b will now be described, with reference to Figs. 7 and 8.

[00106] In a top-down expansion procedure, the tool 22b is run into a well borehole on coiled tubing and into the liner 12b. When the tool 22b has been located at the top of the liner 12b, fluid is circulated through the bore 50b of the tool, exiting through the nozzle 33b. The nozzle 33b restricts fluid flow and increases the back-pressure of fluid in the bore 50b, pressurizing fluid in the cylinder 44b relative to the fluid acting on the lower piston area 31b. The combination of the back-pressure of the fluid in the cylinder 44b and the differential piston area urges the piston 46b downwardly, carrying the mandrel 26b downwardly to the activating position of Fig 8. During this movement, the cam surface 54b of the mandrel cone 52b abuts the roller pistons 20b, urging the pistons radially outwardly in their slots 23b, to the extended configuration of Fig 8.

[00107] At the same time, the tool 22b is rotated by an appropriate downhole motor, or from surface and the rollers 18b are progressively moved outwardly to describe an expansion diameter greater than the unexpanded internal diameter of the tubing 12b. When the mandrel 26b has moved fully downwardly, the snap ring 27b locks out against the guide ring 42b, to lock the mandrel 26b against return movement to the deactivating position of Fig 1. The mandrel 26b is thus locked in the activating position, and maintains the rollers 18b in the extended configuration of Fig 8.

[00108] The rotating expansion tool 22b is then translated axially through the tubing 12b, and the rollers 18b diametrically expand the liner 12b to a greater internal diameter, as shown in Fig. 8. By verifying that the snap ring 27b has locked out to restrain the mandrel 26b in the activating configuration, this indicates to the operator that the rollers 18 were correctly located in the extended configuration during the expansion procedure. Accordingly, this provides an indication that the tubing 12b has been expanded to the desired, predetermined internal diameter described by the rollers 18b in the extended configuration. The snap ring 27b is then released and the mandrel 26b retracts to the deactivating position under the force of the spring 36b, thus de-supporting the rollers 18b. The rollers 18b can then be returned to the retracted configuration of Fig 7.

[00109] Turning now to Figs. 9 and 10, an alternative method of operation of the tool 22b will be described.

[00110] Fig. 9 shows the tool 22b located in borehole casing 32b, in the deactivated position. The tool 22b has been run into the casing 32b on a string together with expandable bore-lining tubing in the form of an expandable liner 66b. An upper end of the liner 66b is shown in Fig. 9, and is located overlapping the casing 32b, with a seal sleeve 68b provided on an outer surface of the liner 66b, for sealing between the casing 32b and the liner 66b.

[00111] When the liner 66b has been located in the desired position, the tool 22b is set down on the upper end of the liner 66b and weight is applied to the mandrel 26b, through the connecting sub 30b. This moves the mandrel 26b downwardly, forcing the rollers 18b outwardly to the expanded configuration, and the snap ring 27b locks the mandrel in the activating position and thus the rollers 18b in the extended configuration. The tool 22b is then rotated and advanced axially through the liner 66b, diametrically expanding the liner into contact with the casing 32b as shown in Fig. 10 (in combination with a mandrel, as described above). The tool 22b is advanced through the liner 66b to a desired depth, and then recovered to surface, as described above. The liner 66b is thus hung from the casing 32b and sealed relative to the casing by the seal sleeve 68b.

[00112] Turning now to Fig. 11 there is shown a further alternative tubing expansion tool 22c. Like components of the tool 22c with the tool 22b of Fig. 7 share the same reference numerals incremented by 100. For ease of reference, only the significant differences between the structure of the tool 22c with respect to the tool 22b will be described herein.

[00113] The tool 22c includes three expansion member assemblies 116c, each comprising expansion arms 70c coupled to the tool body 114c by pivots 125c and an expansion ball 72c rotatably mounted to the arm 70c for expanding tubing. The arms 70c are spaced 120O apart and are moveable about the pivots 125c between the de-activated configuration of Fig. 11 and the expanded configuration of Fig. 12 in

the same fashion as the tool 22b. The mandrel 126c includes a cylindrical lower end 124c and each arm 70c includes an inner surface 156c which is recessed (not shown) to define a cam surface which abuts the mandrel lower end 124c. As the mandrel 126c descends, the mandrel urges the arms 70c, and thus the expansion balls 72c, outwardly to the expanded configuration of Fig. 12. Pivotably mounting the arms 70c on the body 114c in this fashion allows a high expansion ratio of the tubing as there is a relatively large movement of the expansion balls 72c between the de-activated and expanded configurations.

[00114] Turning now to Fig. 13, there is shown a yet further alternative tubing expansion tool 22d. This view of the tool 22d corresponds to a section along line A-A of Fig. 14. It will be understood that the view of the tool 22c shown in Fig. 11 is sectioned in a similar fashion.

[00115] Like components of the tool 22d with the tool 22b of Fig. 7 share the same reference numbers incremented by 200. Again, only the main differences between the tool 22d and the tool 22b will be described herein.

[00116] The tool 22d includes three expansion members 216d spaced 120o apart and including expansion arms 270d pivotably mounted to the tool body 214d by pivots 225d. Tapered, truncated expansion cones 274d are rotatably mounted on spindles of the arms 270d for expanding tubing when the tool is moved to the expanded configuration of Fig. 15. Again, a high expansion ratio is achieved by the relatively large movement of the expansion members 216d, as shown best in Fig. 14, the position of the cones 274d in the expanded configuration indicated by the broken reference line. The tool 22d is otherwise similar to the tool 22c of Fig. 11 and cam surfaces 76d defined by the arms 270d are illustrated in Fig. 13. These cam surfaces 76d abut the lower end 224d of the tool mandrel 226d during downward movement of the mandrel, to urge the expansion arms 270d outwardly to the expanded configuration.

[00117] In further embodiments, the tools 22b, 22c or 22d may be activated through a combination of mechanical force applied to the respective tool mandrel

and through circulation of fluid through the tool bore to force the mandrel downwardly.

[00118] In alternative embodiments of the present invention (not illustrated), an expansion device may be provided incorporating a hoop stress inducing expansion tool of the type disclosed in the applicant's International patent application no. PCT/GB2002/005387, the disclosure of which is incorporated herein by way of reference. PCT/GB2002/005387 discloses expansion tools of the type adapted to be advanced through tubing without rotation, having a number of expansion rollers (some compliantly mounted) located with their respective axes perpendicular to a main axis of the tool. PCT/GB2002/005387 also discloses a hoop stress inducing expansion tool in the form of a compliant cone or mandrel, and expansion arms or fingers, which may be employed in the present invention.

[00119] Reference is now made to Figure 16 of the drawings, which shows a sectional view of a still further alternative expansion tool 22h. The tool 22h comprises a generally cylindrical body 12h (in this example, 197.10 mm outer diameter), the trailing end of the body 12h defining a box connection 14h for coupling to a corresponding pin connection provided on the lower end of a string of drill pipe (not shown), cone, mandrel or the like, as described above. The body 12h defines a throughbore 11h, to allow fluid to be passed through the tool 22h, the throughbore 11h including a recess 13h to accommodate a flow-restricting nozzle if required.

[00120] Mounted on the leading end of the body 12h are three spindles 16h (only one shown), the spindle axes 18h lying parallel to the main body axis 20h. Each spindle 16h provides mounting for a respective expansion member in the form of a 30 degree conical profile 21h. In this example the profiles 21h describe a maximum diameter 23h of 220 mm, as illustrated in Figure 17. The spindles 16h are essentially identical to one another and thus only the spindle 16h illustrated in section in Figures 16 and 18 of the drawings will be described in detail.

[00121] The spindle 16h has a male threaded portion 24h which is received in a complementary female threaded bore 26h in the body end face 28h. The end of the spindle threaded portion also features a groove 30h housing an O-ring seal 32h, and an annular slot 33h for cooperation with a pin 34h which serves to further secure the spindle 20h to the body 12h. The leading end of the spindle, as illustrated in greater detail in Figure 18 of the drawings, has a stepped profile and cooperates with a number of bearings to provide mounting for the conical profile 21h. Three journal bearings 36h, 38h, 40h are provided between the spindle 16h and the profile 21h, which is stepped internally in a corresponding manner, as may be seen from Figure 18 of the drawings. In particular, the bearings comprise a needle roller bearing 36h, a roller thrust bearing 38h, and a taper roller bearing 40h. The free end of the spindle 16h is capped by a brass thrust cap 39h which sits upon a hexagonal wear insert 41h located in a corresponding recess in the end face of the spindle, and which insert wears preferentially to the spindle. Furthermore, each of the spindle 16h and the profile 21h define a respective bearing race 42h, 44h, into which an appropriate number of balls 46h are located via a port 48h in the profile 21h, and which port 48h may be closed by a plug 50h held in position by a circlip.

[00122] The base of the profile 21h defines a groove 52h accommodating an O-ring seal 54h which serves to retain lubricant in the bearing area and also to prevent ingress of material. Lubricant for the bearings is retained within a sealed pressure-compensated system including a lubricant reservoir 60h, one reservoir 60h being provided for each profile 21h. The reservoir 60h is provided by the leading end of a longitudinally extending bore 62h which has been drilled from the trailing end of the body 12h, a piston 64h being movable within the bore 62h in response to external fluid pressure, and the piston being retained in the bore 62h by a circlip 65h. A conduit 66h extends from the reservoir 60h to the base of the spindle 16h. A conical recess 68h in the base of the spindle 16h in communication with the conduit 66h leads to a bore 70h extending along the spindle axis 18h, with branches 72h extending radially from the bore 70h to carry lubricant to the base of the journal bearing seats.

[00123] One face of the piston 64h is exposed to external pressure, while the other face of the piston is in contact with the lubricant in the reservoir. Thus, the piston 64h may move in the bore 62h to compensate for changes in external pressure, in particular the increasing pressure experienced as the tool 22h is lowered into a bore. This minimizes the pressure differentials experienced by the seals 54h, thus increasing seal life.

[00124] In use, the tool 22h is provided as part of an expansion device such as device 10 of Fig. 1, mounted to the lower end of a string of drill pipe and run into a bore. The device carrying the tool 22h may be run into the bore together with a tubular to be expanded, or may be run into a tubular which has been previously located in the bore. The leading end of the profiles 21h are located in the upper end of the tubular, while the tool 22h is rotated and axial force is applied to the tool. As the tool 22h rotates, the profiles 23h are rolled around the inner face of the tubular, and tend to reduce the wall thickness of the tubular such that the diameter of the tubular increases. As the tool 22h translates axially, the tubular is expanded to a diameter similar to the maximum diameter described by the profiles 21h.

[00125] The rotary expansion of downhole tubulars, and in particular solid walled tubulars, subjects expansion tools to significant radial, axial and torsional loads. Furthermore, the expansion of the tubing tends to produce elevated temperatures, both in the tubing and the expansion tool. The provision of the combination of journal and roller bearings within a sealed lubrication system facilitates the free rolling motion necessary to achieve the desired uniform tubular expansion while minimizing induced torque and friction, and hence increased temperature. The tool construction provides a compact and robust arrangement well adapted to withstand the loads experienced in use, and the provision of a pressure-compensated bearing lubrication system reduces the pressure differential across the bearing seals and thus extends seal life. This increases bearing life and thus facilitates use of the tool 22h in the expansion of extended lengths of tubing downhole.

[00126] In addition, those of skill in the art will appreciate that the present tool configuration combines the robustness and uniform expansion of fixed geometry expansion devices with the advantages of the reduced torques and loads required for operation of a rotary expansion device.

[00127] The above embodiment features 30 degree angle profiles, however Figure 19 of the drawings illustrates a profile 80h with a 20 degree angle, which will tend to induce a more gradual expansion.

[00128] Reference is now made to Figures 20 to 23 of the drawings, which illustrate a still further alternative expansion tool 22i. The tool 22i includes five expansion members 102i, each including a tapering leading end portion 104i and a cylindrical trailing portion 106i. The spindles 108i on which the members 102i are mounted are each profiled to accommodate a thrust bearing 110i, a roller bearing 112i and a journal bearing 114i. Although the seals are not illustrated, the tool 22i incorporates a sealed lubrication system, including a lubrication reservoir 115i.

[00129] The tool body 116i has a central portion which extends beyond the expansion members 102i and terminates in a pin connection 118i for coupling to a further part of a tool string, mandrel or the like. Rearwardly of the connection 118i is a cylindrical body portion 120i about which is mounted a contact sleeve 122i of low friction material such as PTFE. The sleeve 122i is in contact with the cylindrical portions 106i of the expansion members, and thus provides radial support for the members 102i.

[00130] The tool 22i is operated in substantially the same manner as the tool 22h described above, but of course does not form the end of the tool string; other tools and devices will be mounted forwardly of the tool 100i, and which may include other expansion tools, as described above.

[00131] Reference is now made to Figures 24 to 26, which show a still further alternative expansion tool 22j. The tool 22j shares many features with the tool 22h described above, including a sealed lubrication system having a lubricant reservoir

202j featuring a pressure-compensating piston (not shown). However, the tool 22j includes three tubing expansion modules 203j mounted in the tool body 206j. Each module 203j includes a spindle 209j and an expansion member in the form of a conical profile or cone 204j. As will be described below, providing an expansion tool with tubing expansion modules allows for quick replacement of any one of the modules in the operational environment.

[00132] Also, unlike the fixed diameter tools 22h, 22i, this tool 22j is compliant, in that the modules 203j including the rotary expansion profiles or cones 204j are mounted to the tool body 206j such that the cones 204j may be individually moved radially inwardly to a limited extent to describe a smaller diameter. This is useful to accommodate, for example, incompressible bore restrictions which prevent the tubing being expanded to a preferred diameter, or variations in tubing wall thickness.

[00133] The tool 22j is illustrated with the cones 204j in the minimum gauge position, hard against respective stops 208j on the body 206j. The cones 204j are each mounted to the spindle 209j which is threaded and pinned in a housing 210j, each housing 210j being pivotally mounted to the body 206j, via respective pins 212j. The pins 212j thus couple the modules 203j to the body 206j and allow the modules to be released from the body, if required. The clearance between the sides of each housing 210j and the slots in the body 206j which accommodate the housings 210j is minimized to ensure that the pins 212j experience only shear, and not bending forces. The degree of compliancy is provided by locating a spring, in this example a stack of three disc springs 214j, between the body 206j and each housing 210j, the degree of outward rotation of the housings being limited by the provision of appropriate stops 215j.

[00134] As with the other tools 22h, 22i, this tool 22j defines a central through bore 216j to allow passage of fluid through the tool body 206j. In addition, three bores 218j branch off from the central bore 216j such that, in use, a cooling jet of liquid may be directed onto the portion of tubing undergoing expansion.

[00135] The sealed lubrication system of the tool 22j, whilst similar in operation to that of the tool 22h, differs in that the lubrication system is provided as an integral part of each tubing expansion module 203j. In more detail, the lubrication system includes a lubrication reservoir 202j in each of the modules 203j. The reservoirs 202j each comprise cylinders formed in the spindle 209j of the respective modules, with a bore 211j extending through the spindle 209j and branches 213j extending radially from the bore 211j to the bearing seats. A piston is mounted in each cylinder 202j to pressure compensate for changes in external pressure.

[00136] In variations in the structure of the tool 22j, the disc springs 214j may be replaced by radially mounted or angled pistons (not shown) in the tool body 206j, for urging the tubing expansion modules 203j outwardly in use, to pivot about the pins 212j. The modules 203j are thus radially inwardly movable against the pistons, in use, to provide a degree of compliancy in the tool. The pistons may be urged radially outwardly on flow of fluid through the tool or supply of fluid in a closed system to the piston.

[00137] Reference is now made to Figures 27 to 30 which show a still further alternative expansion tool 22k. The expansion tool 22k shares many features with the tool 22h described above, including a sealed lubrication system and bores for allowing the passage of cooling fluid through the tool.

[00138] In more detail, the tool 22k includes a generally cylindrical body 302k with three recesses 304k in the outer surface of the body 302k, in which three corresponding tubing expansion modules 306k are mounted. The top and bottom views of Figures 28 and 29 show the relative location of the modules 306k, which are spaced apart by 120 degrees.

[00139] Each of the modules 306k includes a spindle 308k and an expansion member in the form of a conical profile 310k rotatably mounted on the spindle 308k. The profile 310k has a leading end defining a 30 degree angle. The recesses 304k in the body 302k are shaped to receive the spindles 308k, which include a rear end in the form of a curved plate 312k with a cylindrical spindle shaft 314k extending

from the plate 312k. The plate 312k includes a number of mounting holes which receive fixing bolts (not shown) for coupling the spindle 308k to the body 302k. The conical profile 310k is mounted on the cylindrical shaft 314k with a series of journal bearings 316k, 318k and 320k between the conical profile 310k and the shaft 314k, the bearings held axially by lock nuts 322k, 324k. Each module 306k includes a lubrication system similar to that described above with reference to the tool 22h. A lower end 326k of the recess 304k receives the end of the shaft 314k for locating the module 306k in the body 302k.

[00140] After the spindles 308k have been secured in the respective recesses 304k by the fixing bolts, a first restraint sleeve 328k is coupled to the body 302k by a co-operating threaded joint 330k and set screws 332k are located to secure the sleeve 328k against rotation. In addition, a second restraint sleeve 334k is coupled to the body 304k by a co-operating threaded joint 336k, to secure the end of the cylindrical shaft 314k in the lower end 326k of the recess 304k. The spindles 308k are then securely coupled to the body 302k with the conical profile 310k rotatable about the spindle ready for use in expanding tubing.

[00141] The body 302k also includes three bores 338k which extend through the body and having outlets 340k, as best shown in Figure 29. The bores 308k allow cooling fluid to flow to the tubing during expansion.

[00142] The tool lubrication system is similar to that described with reference to the tool 22h, and a conduit 342k of the lubrication system is coupled to the bearing lubrication system and pressure compensated by a piston or diaphragm.

[00143] Provision of the tool 22k including the tubing expansion modules 306k allows for quick replacement of any one of the modules 306k in the operational environment should any of the spindles 308k, conical profiles 310k or the bearings 316k to 320k require replacement or maintenance. In particular, it is not required to disassemble the entire tool to remove the modules 306k, nor to remove the conical profile 310k from the spindle 308k during removal. Instead, to release the modules 306k, the restraint sleeves 328k and 334k are released before removing the fixing

bolts connecting the spindles 308k to the body 302k. The module 306k may then be removed and replaced as necessary. This both cuts down on the time and therefore operating costs of using the tool 300k and provides flexibility in use, as the procedure can be carried out in the operational environment, such as on the rig floor. Alternatively, the tool 300k may be broken-out (released) from a string carrying the tool for subsequent removal of the modules 306k in, for example, a workshop environment.

[00144] In variations in the structure of the tool 22k, the tubing expansion modules 306k may be radially movably mounted (not shown) with respect to the tool body 302k, to provide the tool 22k with a degree of compliancy. For example, the modules 306k may be coupled to or may define a radially movable piston, the piston urged radially outwardly, in use, on flow of fluid through the tool or supply of fluid in a closed system to the piston.

[00145] It will be understood that features of any one of the expansion tools of Figs. 6 to 30 may be provided in combination in alternative expansion devices.

[00146] Various modifications may be made to the foregoing without departing from the spirit and scope of the present invention.

[00147] For example, any one of the expansion tools of Figs. 7 to 15 may only include locking means or biasing means. The tool may be mechanically activated in any alternative fashion suitable for moving the mandrel down relative to the body. For example, the tool mandrel may be urged downwardly relative to the tool body by restraining the body and setting weight down on the mandrel.

[00148] The snap ring may alternatively be disengaged downhole, such that the biasing spring returns the sub and mandrel to the de-activated position. This de-supports the rollers, which are now no longer able to exert an expansion force on the tubing, allowing the expansion tool to be returned to surface more easily. The snap ring may be released downhole by a release assembly such as release sleeve moved over the snap ring to cam the ring into the ring slot, allowing movement of the

mandrel past the guide ring. Alternatively, the tool may include dogs or pins for moving the snap ring inwardly. In a further alternative, the snap ring may simply be sheared out.

[00149] The mandrel may define a piston in place of a floating annular piston mounted on a shoulder of the mandrel, the mandrel shoulder may define the piston. Thus, for example, the annular piston of the tool may comprise an integral part of or may be coupled to the mandrel shoulder.

[00150] The tool may be run on jointed tubing and may be driven from surface by a kelly or top drive.

[00151] Where the expansion members of the tool are mounted on pivots, movement of the mandrel downwardly may rotate the rollers about the pivot such that the rollers describe an expanded diameter for expanding tubing.

[00152] Where the tools are activated by fluid pressure, the respective tool mandrel may be urged downwardly either by providing the mandrel with a restriction nozzle to create a back pressure, or by defining a differential piston area across the floating annular piston, or by a combination of the two, as described above.

[00153] In further alternatives, the tubing expansion modules of any one of the expansion tools of Figs. 16 to 30 may be located at an angle to a main axis of the tubing expansion tool and may be angled towards a leading or lower end of the tool. The lubrication system may be provided with a lubrication fluid reservoir internally or externally of the tool and pressure compensated in any desired fashion such as by piston, diaphragm or the like. The arrangement of bearings in the tools may be any desired combination and may be tailored to the particular expansion procedure to be conducted. The spindles may be releasably coupled to the tool body using any suitable fixings such as screws, shear pins or the like. Whilst some of the above embodiments utilize cantilevered spindles, in other aspects of the invention spindles supported at both ends may be utilized.

[00154] Additionally or alternatively, the expansion member module, and thus the expansion member may be skewed with respect to the main axis of the tool and may, for example, be generally helically oriented. Thus, the expansion member axis may extend at an angle with respect to the tool main axis. Mounting the expansion member skewed with respect to the tool axis causes the expansion member to exert a force on the tool body tending to advance the tool body through tubing being expanded on rotation of the tool body.

[00155] The lubrication system may be adapted to be pressurized such that fluid in the lubrication system is under a higher pressure than fluid outside the system. Such overpressurising of the lubrication system promotes a positive displacement of the lubrication fluid from the system, in use, to prevent ingress of well fluids, solids or other contaminants into the lubrication system. The lubrication system may include a biased piston, for example, a spring biased piston or the like for pressurizing the lubrication system fluid above the pressure of fluid outside the system.

[00156] The expansion members/modules may be at irregular angular spacings with respect to the tool body, if desired.